TECHNICAL NOTES

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THE FAIRING OF AIRFOIL CONTOURS.

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Although a great many attempts have been made at improving the performance of airfoils by abrupt changes in contour, producing what are commonly described as freak sections, none of them have achieved any real success. A study of the whole literature of the subject reveals no instance where good all-round results have been given by any airfoil having an abrupt change in contour or a discontinuity either in slope or curvature anywhere except at the leading and trailing edges.

If it be accepted as a fact that good results with a wing section can only be obtained by making it of smooth form, the importance of accurate and simple means of fairing the contours, whereby the smoothness of their outline can be quickly determined, becomes evident. Various mechanical, graphical and analytical devices for fairing have, of course, long been known to and used by naval architects, but their use by designers of aircraft seems to have been rather rare. A certain amount of work has been done on the fairing of fuselages, an analytical method having been developed by Mr. Allen Loomis,* but the fairing of airfoil contours, which is very much easier and at least as important, has been substantially neglected. The result of the failure to study the smoothness

* "Scientific Fairing of Veneer Fuselages," Bulletin of the Airplane Engineering Division, U.S.A., October, 1918, pp. 56-65.

of the contours by any special device results in the production of a very large number of unfair airfoil forms. The writer's experience while in charge of the operation of a wind tunnel has been that at least 50% of the airfoil sections of which private individuals and companies send in the ordinates and drawings in order that the models may be constructed and wind tunnel tests made, are imperfectly faired and can be improved in smoothness by very slight adjustment of the ordinates.

Imperfect fairing is inevitable if, as is usually the case, reliance is to be placed on a simple direct drawing of an airfoil section, no matter what the scale employed. It is a common practice to draw a section up on a chord of three or four feet length and then to consider it as faired if no irregularity is evident to the eye in looking along the curve. That test is a very crude one, however. Even on a four-foot chord length the breadth of an ordinary ink line is an important fraction of the ordinate, and the almost unconscious fairing done by the draftsman is enough so that the curve may appear perfectly smooth as drawn, and yet when a model is made exactly to the specified ordinates it may prove to have a whole series of ridges and hollows in the upper or lower surface or both.

The most obvious device for fairing a contour is simply to plot it in a foreshortened form, the ordinates being enlarged to several times their true proportion as compared to the abscissae. This is the method which is usually most convenient of application to the lower surface of a wing. Its use in that connection is illustrated in Fig. 1, where the contour of the lower surface of the R.A.F.6 is plotted from the original British ordinates.* The curve has first been plotted directly and in its true form from the ordinate as given. It will be observed that the curve is almost a straight line and that it is impossible to detect any appreciable deviation between the marked points and the curve. Lower down in Fig. 1, the same ordinates are plotted to a scale enlarged 20-fold, the scale of the abscissae (distances along the chord) remaining unchanged. The dotted curve actually passes through the points as plotted and its unfairness is now obvious. It could hardly escape notice even if the curve had been very roughly plotted, whereas the most careful and accurate draftsmanship would have been required to gain any information from the original undistorted curves. By a very small modification of the ordinates at a few of the stations the curve can be smoothed out as shown by the full line. The trouble here was not so much due to incorrect specification of the ordinates as to insufficiently complete specification, the heights of the lower surface being given to only one significant figure and a variation of one digit corresponding to .006" on a wind tunnel model of 6-inch chord, while a metal model made by the best means now available can be considered correct within .001". The inclusion of at least one additional significant figure in the tabulation of ordinates would therefore be justified. The original ordinates as specified for the lower surface are given below, side by side with the corrected ordinates being given to two significant figures instead of only one.

* Technical Report of the British Advisory Committee for Aeronautics, 1912-13, Page 89.

It will be observed that the maximum change of ordinate is .0007 of the chord, a very small change but not an entirely negligible one.

Distance from leading edge.	Original ordinates.	Faired ordinates
0	0	0
.05	.002	.0022
.1	.004	.0042
.2	.007	.0068
.3	.008	.0077
.4	.007	.0070
.5	.005	.0057
.6	.004	.0043
.7	.003	.0030
.8	.002	.0018
.9	.001	.0008
1.0	0	0

The same method can, of course, be used for fairing the upper surface, and the application to this same wing is shown in Fig. 2, where the wing has been plotted to normal size and also with the ordinates elongated 6-fold. It is evident from inspection of the foreshortened curve that some improvement can be made in the smoothness at a couple of points.

With a curve as deep and as changeable in form as that for the upper surface of an airfoil is likely to be, better results can be secured by another method of fairing. If each of two curves are smooth in form, the curve of differences between them should also be smooth. It therefore suffices to choose some analytic curve of simple form and to plot a curve of differences between the ordinates of that datum curve and the actual wing contour. The most convenient analytic curve for this purpose is, of course, a straight line, and a straight line serves very well in many instances, particularly for the rear part of the upper surface. As an illustration, curves of differences of ordinate have been plotted in Fig. 3, with respect to three straight lines, one each planned especially to take care of the forward, the middle and the rear portions of the upper surface contour. The lines themselves are indicated on the drawing at the top of the figure, and also defined by their equations, and the differences of ordinates are plotted exaggerated 10-fold. The irregularity of form on the rear part of the upper surface now shows up very clearly on curve 3 in Fig. 3, and it is evident that the smoothness would be improved if the two ordinates immediately forward of the trailing edge were changed from .027 to .0263 and from .044 to .0435 respectively, as shown by the dotted line adjacent to curve 3.

The only objectionable feature of the method of fairing just described is that a single line cannot be made to fit the whole contour, and there is likely to be trouble in getting a smooth outline at points near the juncture of the various fairing curves. It is desirable therefore that we seek still further for a comparatively simple analytic curve which will serve our purpose, and one suitable for most contours is found in the parabola.

A parabola can be drawn to pass through any four points, or to pass through any three points with any desired slope at one of them. In particular, a parabola may be constructed to coincide with the contour of the upper surface of the wing at the leading and trailing edges and at the maximum ordinate, with a zero slope at the latter point. If the chord of the wing be so drawn as to connect the leading and trailing edges of the upper surface, and if the length of the chord be taken as the unit of measurement, the general equation of the parabola is:

$$2hx^2 + 4xy\,(.5 - m) + \frac{2y^2}{h}\,(.5 - m)^2 - 2hx + y\,(2m - .5) = 0,$$

where x is the distance along the chord from the leading edge, y the distance above the chord, m the distance from the leading edge to the point of maximum camber, and h the height of the contour above the chord at that point. In the particular case of the R.A.F.6, if the chord be assumed raised by .005 times its own length, to bring it in contact with the leading and trailing edges of the upper, rather than the lower, surface, m is .3 and h is .07 the equation takes the form:

$$.14x^2 + .8xy + 1.143y^2 - .14x + .1y = 0,$$

or, multiplying by a constant to eliminate the fractions,

$$49x^2 + 28xy + 400y^2 - 49x + 35y = 0.$$

Solving for the ordinates at various stations along the new chord, (.005 above the original one), the values tabulated below are obtained.

Distance from leading edge	Ordinate of parabola	Ordinate specified for R.A.F.6	Difference of ordinate
0	0	0	0
.025	.0233	.0270	+.0037
.05	.0326	.0390	+.0064
.1	.0525	.0550	+.0025
.2	.0666	.0690	+.0024
.3	.0700	.0710	+.0010
.4	.06755	.0700	+.00245
.5	.0614	.0660	+.0046
.6	.0525	.0600	+.0075
.7	.04155	.0520	+.01045
.8	.02895	.0390	+.01005
.9	.01505	.0220	+.00695

The results are shown in Fig. 4. The original R.A.F.6 section is again plotted in true scale near the top of the sheet, and the differences of ordinates between the parabola and the wing contour are plotted with the ordinates enlarged 20-fold in the curve in the lower portion of Fig. 4.

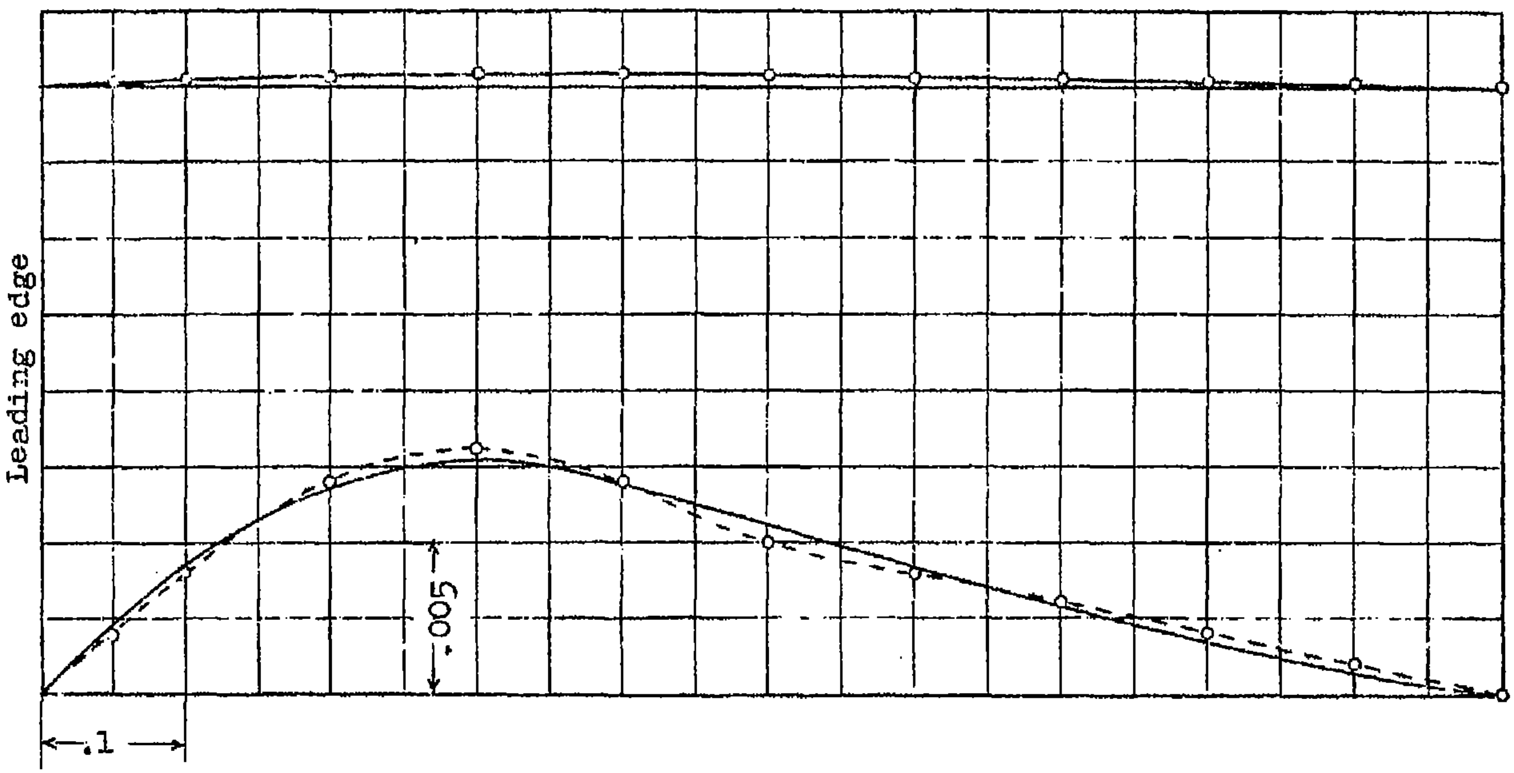

Fig.1.

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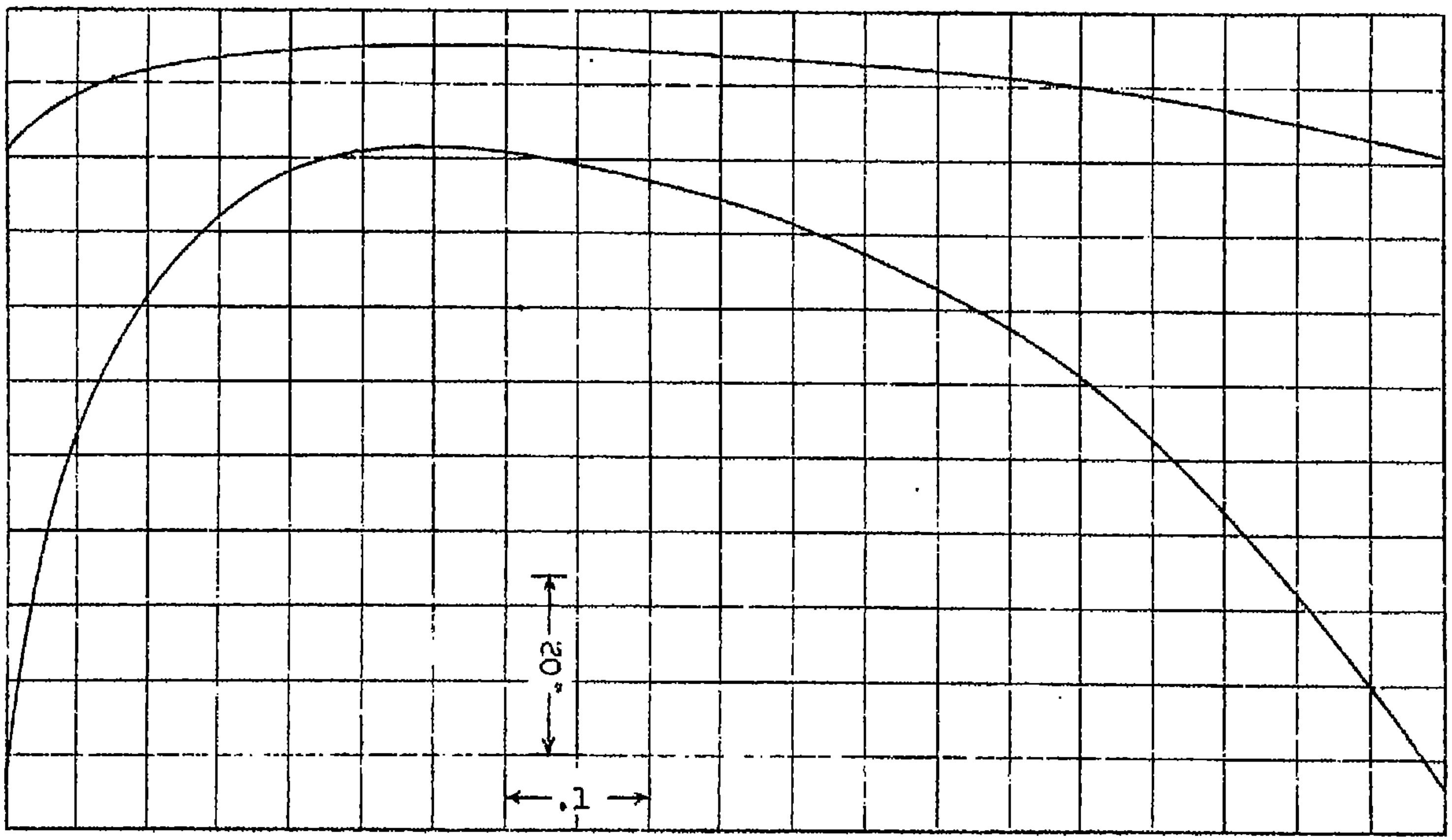
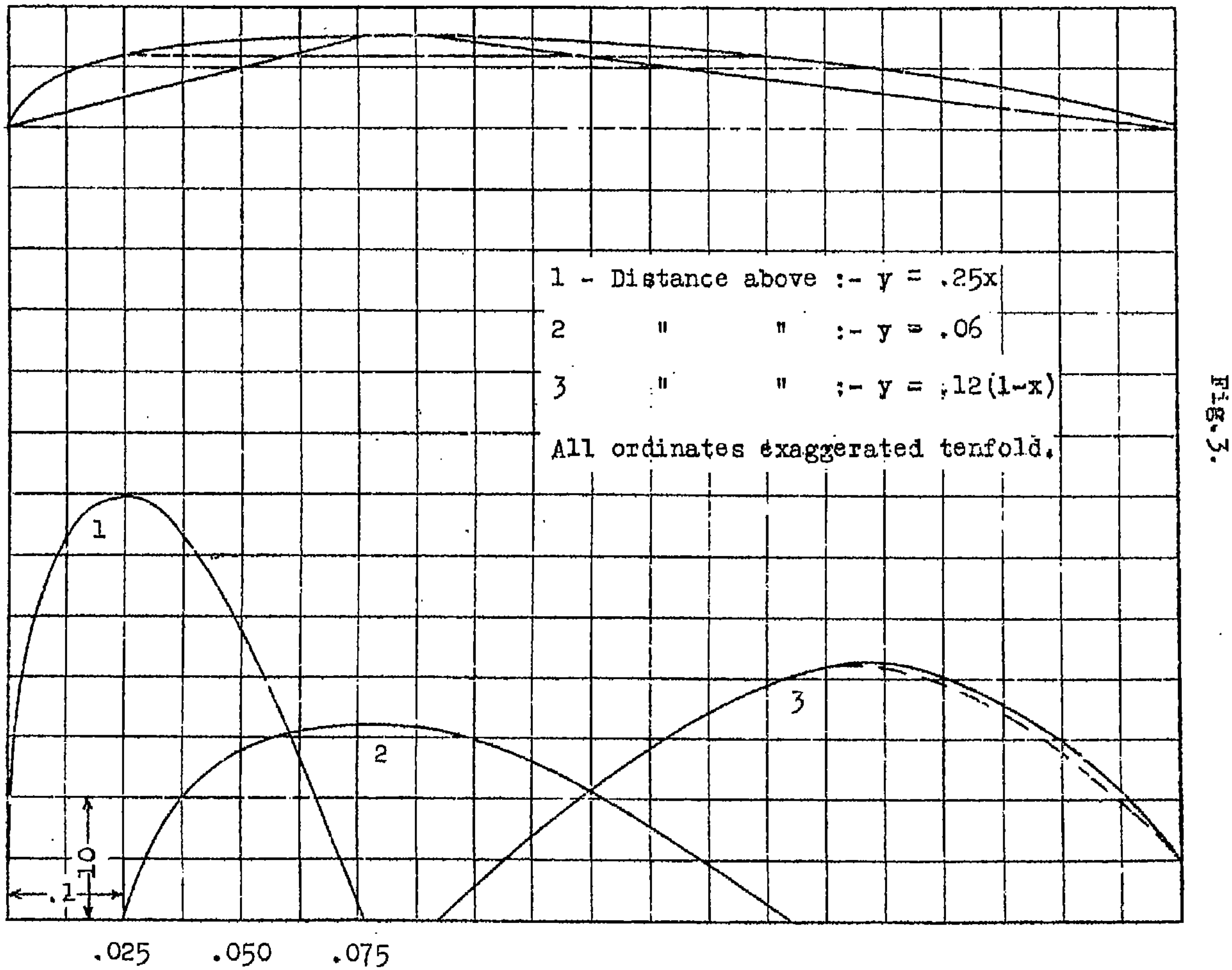


Fig.2.

Fig.2.


1 - Distance above :- y = .25x
2 " " :- y = .06
3 " " :- y = .12(1-x)
All ordinates exaggerated tenfold.
1
2
3
.1
.10
.025
.050
.075
Fig. 3.

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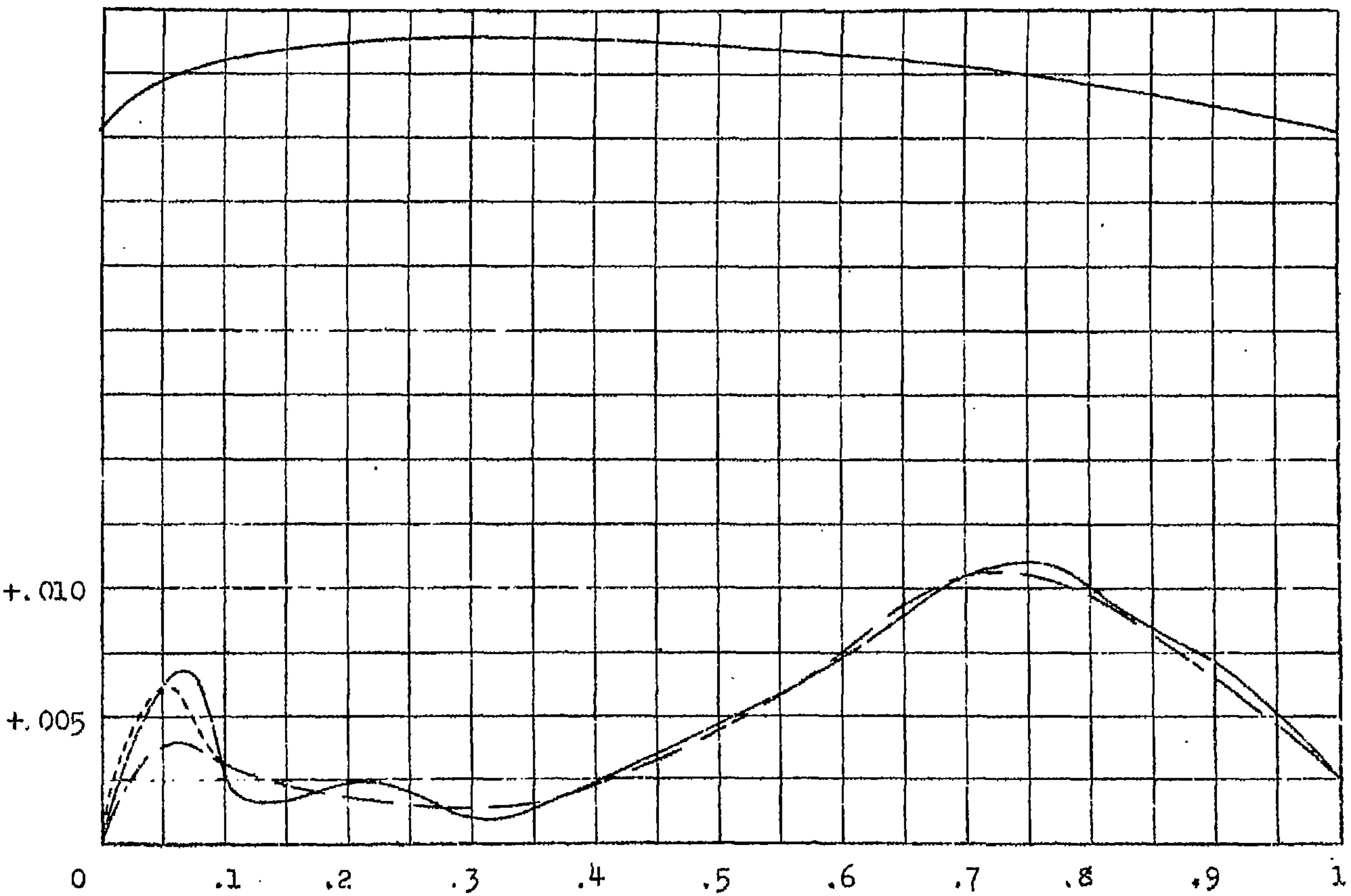

Fig.4.

Fig.4.